eRD22 GEM-TRD/T R&D Progress Report

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Project ID: eRD22
Project Name GEM based Transition radiation detector and tracker
Period Reported: from 07/2018 to 07/2019
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Abstract

Transition radiation detectors are widely used for electron identification in various particle physics experiments, such as ALICE, ATLAS, HERMES, etc. For a high luminosity electron-ion collider a high granularity tracker combined with a transition radiation option for particle identification could provide additional electron identification/hadron suppression. Due to the low material budget and cost of GEM detector technologies, a GEM based transition radiation detector/tracker (GEM-TRD/T) is an ideal candidate for large area hadron endcap where a high flux of hadrons is expected at the EIC.

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1 Introduction

Identification of secondary electrons plays a very important role for physics at the Electron-Ion Collider (EIC). J/ψ has a significant branching ratio for decays into leptons (the branching ratio to electrons (e^+e^- pair) is at the order of 6%) and it is the simplest two-body decay process used to identification of J/ψ. The branching ratio of D-mesons is Br($D^+ \rightarrow e + X$) $\sim$ 16% and the branching ratio of B-mesons is Br($B^\pm \rightarrow e + \nu + X_c$) $\sim$ 10%. Electron identification is also important for many other physics topics, such as spectroscopy, beyond the standard model physics, etc. The improved electron identification would allow to reduce combinatorial background and improve event selection efficiency.

The scope of this project is to develop a transition radiation detector/tracker capable of providing additional pion rejection (>10-100). A high granularity tracker combined with a transition radiation option for particle identification could provide additional information necessary for electron identification or hadron suppression.

2 PAST

- *What was planned for this period?*
  This is the second year of the eRD22 project. The advisory committee recommended focusing on a GEANT4 simulation of the GEM/TRD setup in the first stage of the project. Our goals were to simulate a GEM-TRD setup, optimize the setup for better electron identification, build a prototype and perform the test-beam measurements, which would allow us to compare a simulation and a real response of the detector.

- *What was achieved?*

GEM-TRD/T concept

The GEM-TRD/T concept is shown in Fig. 1.

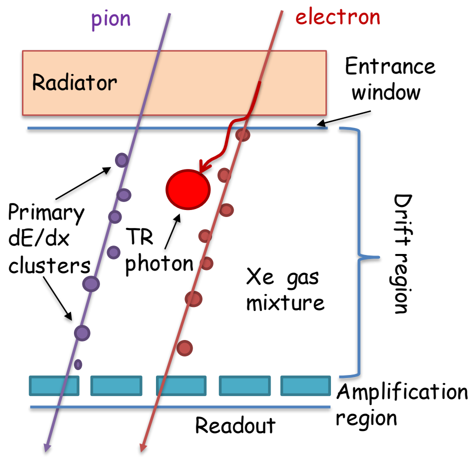


Figure 1: GEM-TRD/T operation principle.

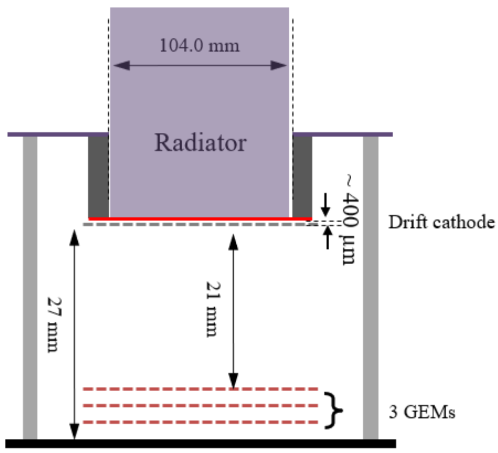


Figure 2: Schematic of GEM-TRD/T prototype.

GEANT4 simulation

We performed a GEANT4 simulation and optimized the radiator and detector thicknesses for a single chamber (Fig. 3), described in the previous report in more detail.

GEANT4 has classes for simulation of TR photons. The classes include models for regular radiators (G4XTRRegularRadModel) and irregular, gamma-distributed radiator foils with gas gaps between the foils (G4XTRGammaRadModel). Both models can be transparent or can take into account TR photon absorption. We used G4XTRGammaRadModel model for our fleece radiator, which could be simulated in GEANT4 as an irregular type of radiator with a certain density and two parameters (α_1, α_2), which define a spread of materials and air-gaps within a radiator. We optimized the thickness for a TR-radiator. Due to the self-absorbing property of the radiator,

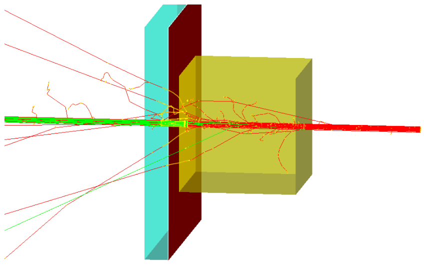


Figure 3: Geant4 simulation of TRD setup, including dead-regions at en trace-window.

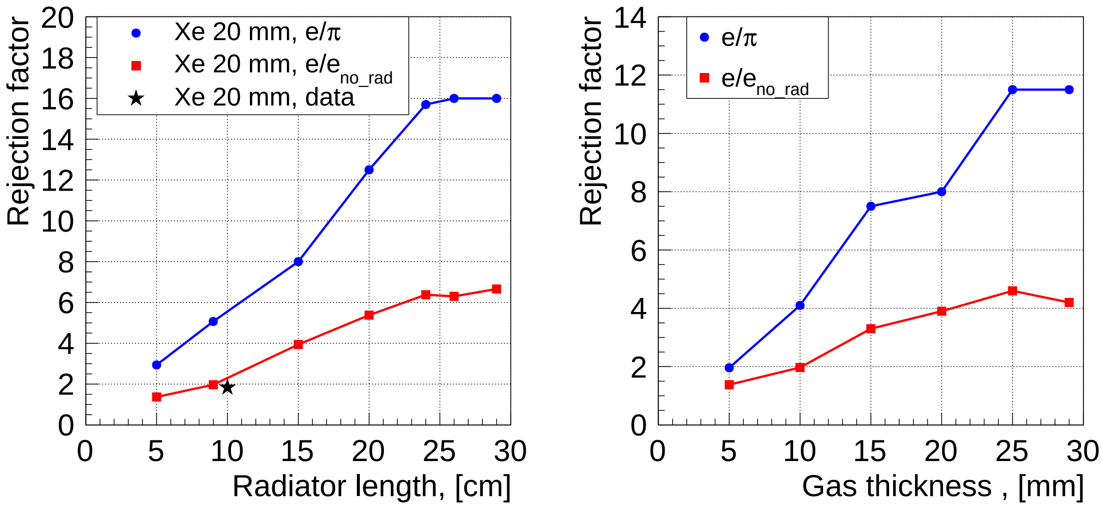


Figure 4: Rejection as a function of a thickness of a TR-radiator (left) and Xe-based detector thickness (right)

soft photons (3-6 kEv) generated within first few centimeters of the TR-radiator will be absorbed, leading to an increase in the hard X-ray photon spectrum at the exit from a radiator. A thin layer of gas in Xe-based detector will not be effective at detecting hard X-ray photons.

As one could see in Fig. 4 (left), rejection power is saturated after 22cm of radiator for our GEM detector with 21mm gas thickness, including 400μm of dead gas layer in front.

Simulation of the detector drift-volume includes a simulation of "dead-material", which consists of 75μm of mylar-foil and 400μm of Xe-filled gap between the drift-cathode and the entrance window, as shown on Fig.3. The presence of this "dead"-region, leads to an inefficiency of low energy TR-photon absorption and has to be minimized.

Fig. 4 (right), also shows saturation of the rejection power for a gas thickness more than 25mm, for a radiator thickness of 15cm.

Table 1 summarizes the rejection power for different radiators and Xe-filled detector volumes.

First test-beam measurements and comparisons with simulation

During this half of the year we focused on a calculation of e/π rejection factor using simulated data, as well as the extraction of e/π rejection using real data (e/$e_{without\ rad}$).

During the last year we performed test beam measurements with a GEM-based transition-radiation detector, described in the previous reports in more detail, using an electron beam provided at the JLAB/Hall-D facility. We used a prototype, assembled at UVA, which had a 2.1 cm of drift-volume (Xe-gas thickness), as well as a 9cm of fleece TR-radiator.

We performed the first measurements of GEM-TRD/T prototype with a Xe gas mixture. A comparison of the detector responses with and without radiator is shown in Fig. 5 left plot (red and blue lines respectively). We performed a test with different radiators. We used ZEUS-TRD

Detector	Dead material in front	Radiator	e/π	$e/e_{no\ radiator}$	$DATA_{e/e_{noR}}$
20 mm	no dead material	20 cm	14.4	6.3	
20 mm	400 μm Xe, Kapton 75μm	20 cm	12.5	5.38	
20 mm	as above	5 cm	2.94	1.37	
20 mm	as above	9 cm	5.07	1.97	1.8
20 mm	as above	15 cm	8.0	3.94	
20 mm	as above	26 cm	16.0	6.3	
20 mm	as above	29 cm	16.1	6.66	
29 mm	400 μm Xe, Kapton 75μm	15 cm	11.5	4.22	
25 mm	as above	15 cm	11.55	4.62	
15 mm	as above	15cm	7.54	3.33	
10 mm	as above	15 cm	4.01	1.97	
5 mm	as above	15 cm	1.96	1.38	

Table 1: Rejection factor corresponding to 90% of electron efficiency.

radiator material (PP fibers with a random in 2D (X-Y) fiber orientation, and material density of 0.083g/cm^3) (Fig. 5 left plot). We also performed a test with a regular structure radiator which had ca. 200 13μm Mylar foils separated by 180μm spacers made from nylon netting. The performance of our system with this type of radiator is shown in Fig. 5 (right).

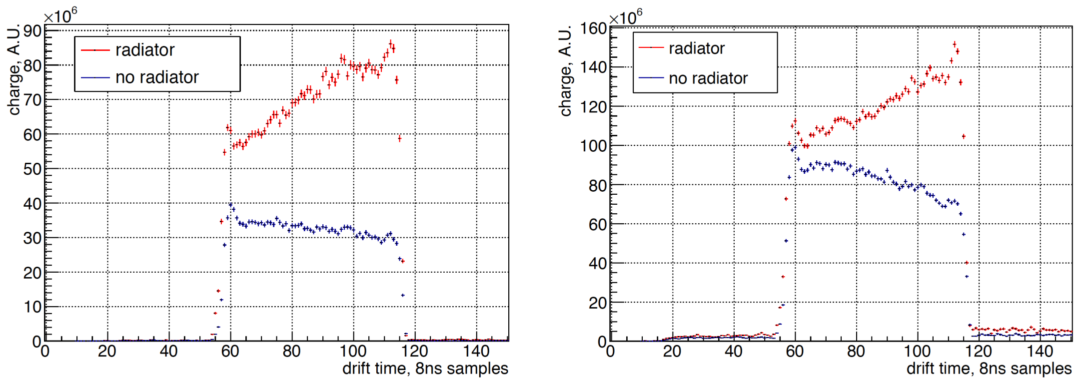


Figure 5: Preliminary results with different radiator materials: fleece (left) and regular foils (right)

Since we had only an electron beam, we compared only the electron response of the detector in two configurations with radiator and without radiator, where the detector response without a TR-radiator was used to "mimic" a pion response.

The difference between e/π rejection factor and $e_{with\ radiator}/e_{no\ radiator}$ TR-radiator for different thicknesses of radiator and Xe-based detectors is shown on Table 1. As one could see, due to a lower average dE/dx for pions, compared to electrons, e/π rejection factor is much higher then for $e_{with\ radiator}/e_{no\ radiator}$ case.

For the e/π rejection factor we analyzed the amplitude and arrival time of each individual cluster along the drift time. We also calculated the total number of clusters and the number of clusters within sub-segments (the total drift distance was subdivided into 20 slices(Fig. 6)). This allowed us to study the number of clusters as well as the average energy loss within a sub-segment of the drift volume.

All this information (upto 20 variables) was used as input for likelihood and artificial neural network (ANN) programs, such as JETNET or ROOT-based (Multi-layer Perceptron). The ANN system was trained with MC or data samples of incident electron and pions. Then an independent sample was used to evaluate the performance. An example of such a training procedure is shown in Fig. 6.

We require a 90% efficiency for our electron identification. The neural network output for e/π identification is shown in the upper two plots of Fig 7 and $e_{with\ radiator}/e_{without\ radiator}$ is shown in the two bottom plots.

The Root-based neural-network (Multi-Layer Perceptron) output for a single module (left) and

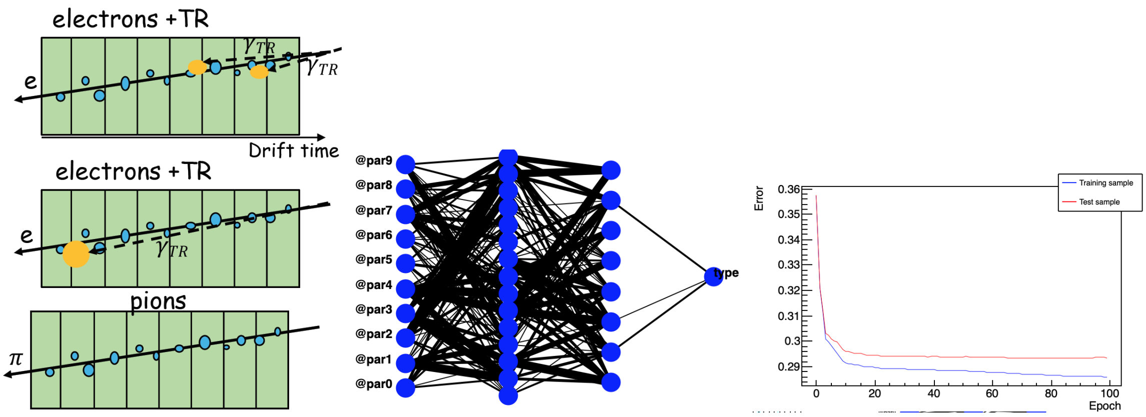


Figure 6: Schematic view of regions along the drift time used for e/*pi* identification (left). Training procedure with Root-based ANN (middle) and ANN training efficiency (right).

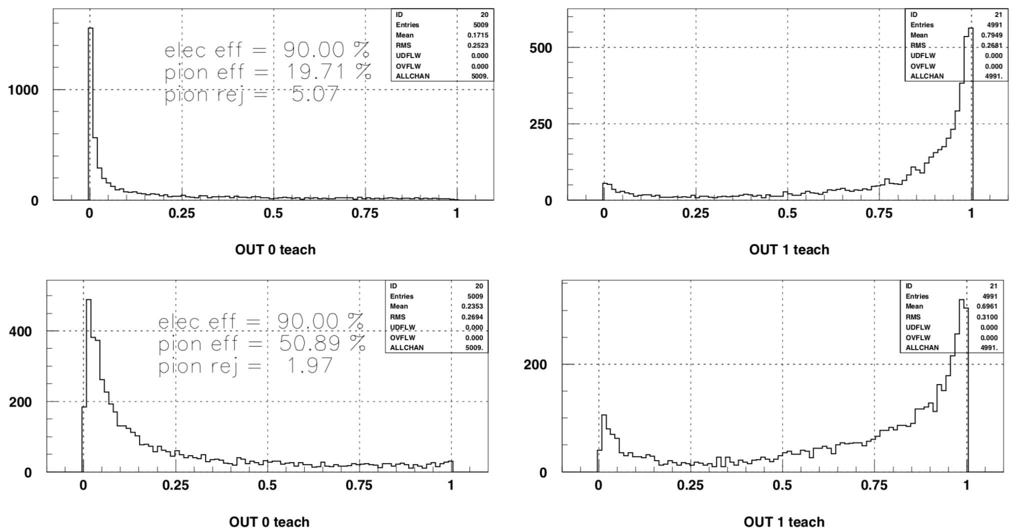
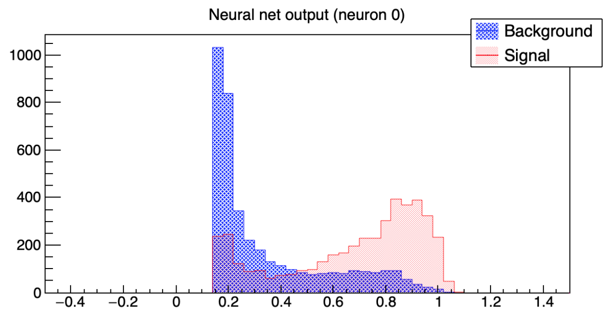


Figure 7: Neural network output for e/π identification (upper plots) and for electrons with radiator and without radiator(bottom plots) for Monte Carlo samples.

propagation for 3 modules (right) for real data sample are shown in Fig 8. Signal histogram (red) on these plots corresponds to electrons passing through radiator and background histogram (blue) corresponds to electron signal without radiator.

As was mentioned above, we performed the test-beam measurements with only an electron beam. The pion rejection was estimated using Monte Carlo as a response for electrons without radiator (e_{wr}). A pion efficiency (e_{wr}) as a function of electron efficiency for a single module (left) and sets of 3 modules (right) is shown on Fig. 8. For electron efficiency of 70%, the pion efficiency is ca. 20% which corresponds to a pion rejection factor of 5. For 3 modules with 70% electron efficiency, pion efficiency is ca. 2% (or a rejection factor 50).



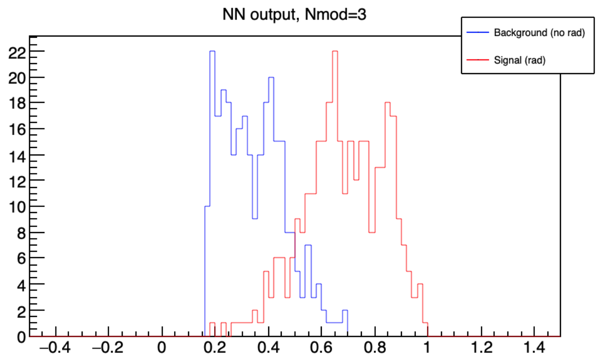


Figure 8: Multi-layer Perceptron output for a single module (left) and propagation for 3 modules (right) for real data sample ($e_{with\ radiator}/e_{without\ radiator}$).

Spring-2019 test-beam measurements

For the spring beam test we planned to perform:

- the test of new Chromium GEM/TRD prototype
- test of the new gas system, which would allow operation with different gas-mixtures
- test of gas purity with a newly purchased gas chromatograph
- study tracking properties of GEMTRD prototype, by using two additional GEM detectors as reference tracker.

A new prototype with Chromium GEM foils (Cr-GEMTRD) has been assembled and tested at UVA, and it is based on the exact same design as in Fig. 2 with the only modification being that the standard Copper GEM foils will be replaced by Chromium GEM foils. The first(previous) prototype with standard Copper GEM foils has been re-assembled and tested at UVA (Fig. 9).

In order to test tracking properties of our GEMTRD prototype, two standard GEM modules have been installed in the same setup (in collaboration with RD6) and have been integrated to our Data Acquisition System, providing a reference measurement of particle trajectory.

Our gas mixing system would allow to perform measurements with different gas mixtures. It was been delivered from Temple University to JLAB (Hall-D) in January. Unfortunately due to safety regulations at JLAB, additional plumbing has to be installed. We are planning to get a final approval by the end of this summer.

To investigate the non-uniformity of dE/dx along the drift volume as well as for monitoring and controlling of the gas-purity a new gas chromatograph has been purchased. It is in the process of calibrated.

A new GEM-TRD/T prototype with Cr-foils has been installed in the test beam setup for the fall. HV powering and noise/pedestals measurements have been performed. Unfortunately, during the HV powering of all GEM modules (including standard GEM trackers) a few uncontrolled HV jumps occurred, which damaged the GEM-TRD/T prototype. It has now been removed from test-beam and is currently under investigation at UVA. We suspect that the HV jumps were due

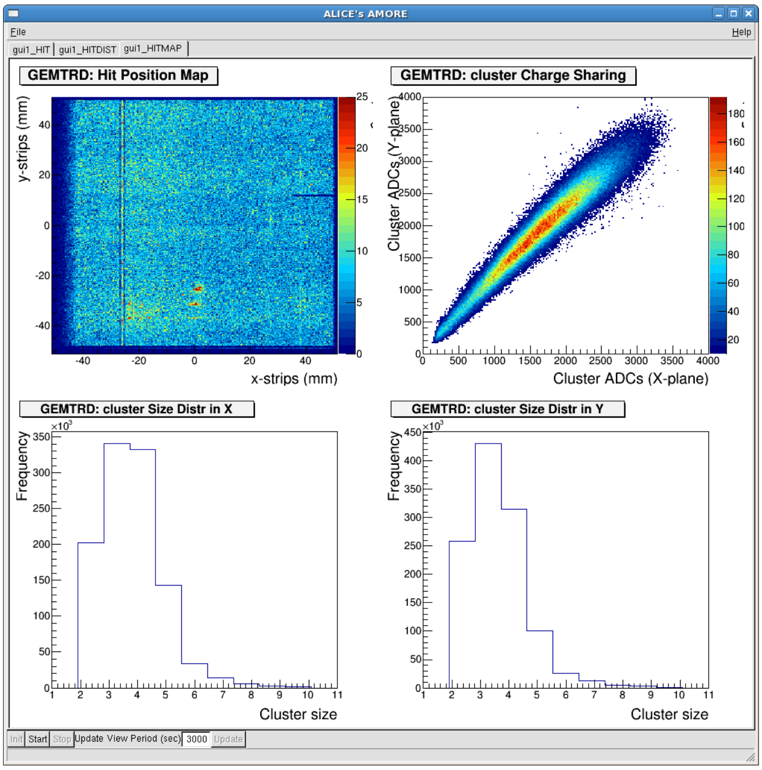


Figure 9: Performance of GEM-TRD module with Fe^{55}.

to using small NIM crates to power the HV modules.

GEM-TRD/T wave form and tracking performance

Since we where not able to continue our data taking before a full investigation and possible repair, the second half of the year has been dedicated to finalizing our results, reporting them at conferences, and publishing them in a peer-reviewed journal (NIM-A).

The standard readout for GEM detectors is typically based on an APV25 chip and measures the peak amplitude. A TRD needs additional information about the ionization along the track, to discriminate TR photons from the ionization of the charged particle. The GEM-TRD/T prototype used a precise (125 MHz, 12 bit) FADC, developed at JLAB, with a VME-based readout. The FADCs have a readout window (pipeline) of up to 8 μs, which covers the entire drift time (500ns) of the GEM-TRD/T prototype and gives a room for HV scan. Pre-amplifiers had GAS-II ASIC chips, which provided 2.6 mV/fC amplification with a peaking time of 10 ns. A typical waveform signal, analyzed with the FADC system is shown in Fig. 10.

We improved our cluster finding and track fitting algorithms. A standard GEM plane can only provide the 2D X-Y position of a track, while the GEM-TRD/T with increased drift volume and with Flash ADC readout allows for 3D track segments to be reconstructed, similar to that of a μTPC. Figure 11 shows an example of a reconstructed 3D track measured with the GEM-TRD/T in projections. The left panel shows the 2D Z (drift time) vs. X position of the strips, The right panel shows the corresponding 2D for the Y position.

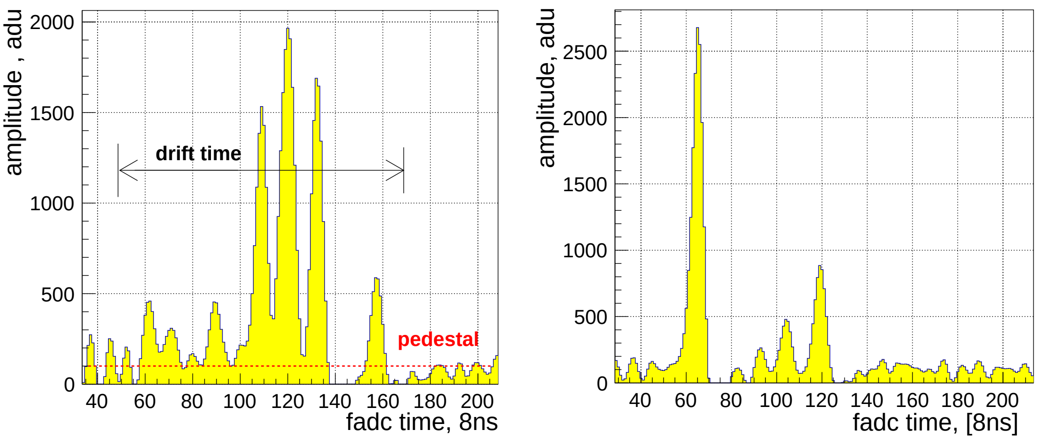


Figure 10: Typical flash ADC waveform.

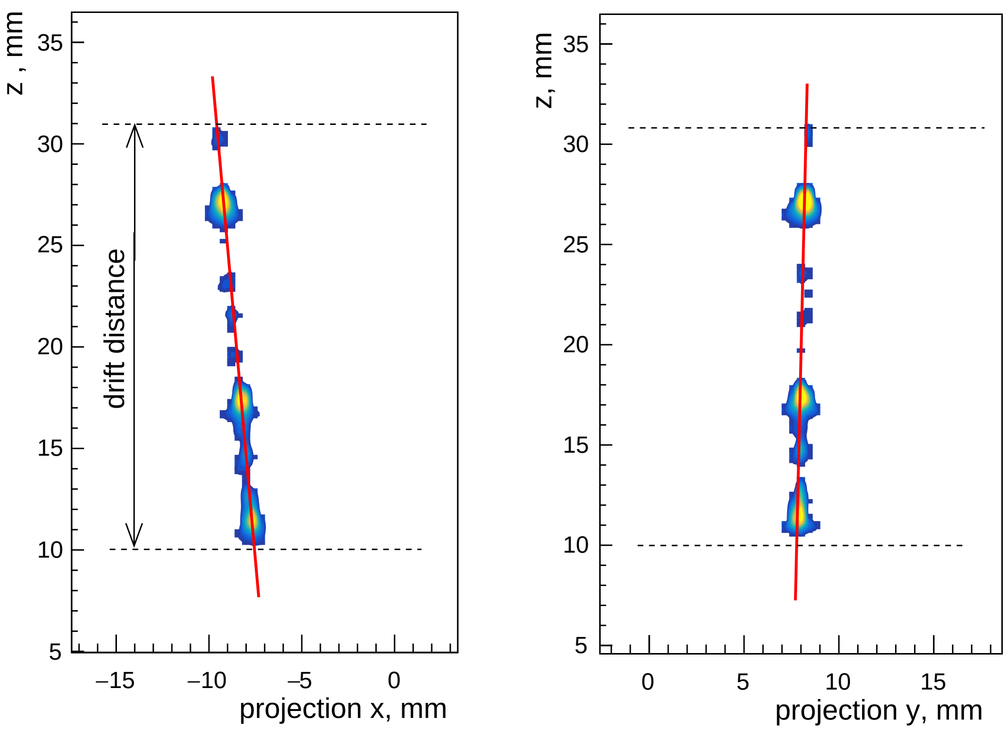


Figure 11: Single track reconstruction.

3 PLANS

3.1 *What is planned for the next funding cycle and beyond? How, if at all, is this planning different from the original plan?*

Due to unexpected difficulties with powering of the prototype, the beam test measurements will be performed in the fall 2019 instead of spring 2019. Both prototypes are intended to be tested this fall in Hall-D at JLab to compare the effect of the GEM Copper electrode on the overall detection efficiency in Xe mixture gas. The gas mixing system is completed, operational and ready to use during our next test beam measurements.
Data analysis of our previous test beam has been finalized. Our results have been reported at the VCI19 conference and at MPGD19 conference and very well received. All our results have been summarized and submitted for publication. We are currently waiting for reviewer comments.
We are planning to assembled a third GEM-TRD prototype with a dedicated field cage to have better control of the field uniformity inside the chamber. So far with the first two prototypes, we had a homemade field cage system that was retro fitted into a standard CERN triple GEM kit. Although we were able to operate and produce some very encouraging results with this prototype, the chamber was far from optimized and the field uniformity inside the detector was just approximate. We will design and build a prototype with a dedicated field cage unit that will be tested and compared the performance to our current prototypes.

3.2 *What are critical issues?*

We have identified a several issues and studies which should be pursued in addition to those in our original plans as important steps towards the realization of a new generation of transition radiation detectors as a part of the EIC project.

- **pion beam.**
  our MC studies showed that for pions e/π rejection will be much better compared to our current test with just electron beam ($e/e_{withoutradiator}$) due to a relativistic rise of dE/dx spectra. In the ideal case, we would like to repeat our measurements with hadron beam (Fermilab or CERN-SPS). In order to do so we need to have our own, standalone readout system (currently we are borrowing it from Hall-D, and it is not movable outside of JLAB).

  We are planning to continue our collaboration with the streaming readout consortium (eRD23) to work together towards a realization of inexpensive readout chips which would allow us to use it for future GEM-TRD prototypes. An inexpensive readout would allow us to check the performance of a GEM-TRD system with multiple layers and would allow us to perform a test with electron and pion beams at Fermilab or CERN. It would be ideal also to perform such a test together with calorimeter and other PID detectors, who could provide independent measurements of particle id, for a cross-check.

  As an initial estimation, we are planning to perform a test with pions coming from decays of ρ-mesons using the Glue-X detector. In the fall, Glue-X experiment will perform a commissioning run of DIRC detector. We are planning to install our prototype in front of the DIRC detector and integrate our GEM-TRD readout into the Glue-X data-acquisition system. This setup would allow us to use the GlueX physics analysis and reconstruction chain necessary for the pion extraction and would allow us to estimate the real e/π rejection factor for our GEM-TRD prototype.

- **radiators.**
  after consulting with CERN (ATLAS), HERMES and ZEUS experts we contacted manufactures (in Europe) who provided TRD-radiators for those experiments, and were told that such materials are no longer in production. Since we have a working setup for TRD measurements in JLAB Hall-D, we are planning to perform a test of new materials, that are currently available for purchasing.

- **machine-learning application on FPGA for an online PID**
  our project got extra support from JLAB, and we are planning next year to work towards of implementation of online particle identification machine-learning application on FPGA. This project would allow us to also use different sub-detectors, such as calorimeters or rich detectors to provide global PID information in the early stage of data processing.

4 Additional information

Manpower *Include a list of the existing manpower and what approximate fraction each has spent on the project. If students or postdocs were funded through the R&D, please state where they were located, what fraction of their time they spend on EIC R&D, and who supervised their work.*

None of JLAB, Temple or UVA members are funded by EIC R&D.

Jefferson Lab (JLAB):
F. Barbosa Electrical Engineers 10%
H. Fenker Research Scientist 5 %
S. Furletov Research Scientist 5 %
Y. Furletova Research Scientist 20 %
L. Pentchev Research Scientist 5 %
C. Stanislav Technical Staff 10%
B. Zihlmann Research Scientist 5 %

Temple University :
M. Posik Research Scientist 15 %
B. Surrow Professor 10 %

University of Virginia (UVa):
K. Gnanvo Research Scientist 20 %
N. Liyanage Professor 5 %

The table 2 below summarizes the Temple University budget request for FY19.

Table 2: **Temple University-Gas System** FY20 request.

	Request	**-20%**	**-40%**
Gas supplies	\$3,000	\$2,000	\$1000
Travel	\$3,000	\$2,000	\$2,000
Overhead (58.5%)	\$3,510	\$2,340	\$1,755
Total	**\$9,510**	**\$6,340**	**\$4,755**

The table 3 below summarizes the Jefferson Lab budget request for FY20.

Table 3: **JLAB: Xe-gas and safety** FY20 request.

	Request	**-20%**	**-40%**
Gas safety	\$4,000	\$2,000	\$2,000
Xe Gas	\$15,000	\$ 15,000	\$ 8,000
Travel	\$5,000	\$4,000	\$3,000
Overhead (ca 12%)	\$3,010	\$2,550	\$ 1,696
Total	**\$27,010**	**\$23,550**	**\$14,696**

The table 5 below summarizes the University of Virginia budget request for FY20.

Table 4: **UVA prototyping** FY20 request.

	Request	**-20%**	**-40%**
GEM-TRD with dedicated field cage	\$6,000	\$5,000	\$4,000
Repair parts for prototype	\$4,000	\$3,000	\$2,000
Travel	\$5,000	\$4,000	\$3,000
Overhead (61.5%)	\$3,075	\$2,460	\$1,855
Total	**\$18,075**	**\$ 14,460**	**\$10,845**

The table 4 below summarizes a total budget request for FY20.

Table 5: **A total eRD22** FY20 request.

	Request	**-20%**	**-40%**
JLAB	$27,010	$23,550	$14,696
UVA	$18,075	$ 14,460	$ 10,845
Temple U	$9,510	$ 6,340	$ 4,755
Total	**$54,595**	**$ 44,350**	**$30,296**

4.1 Publications

Please provide a list of publications coming out of the R&D effort.

Conference talk at MPGD2019.
Conference talk at VCI2019.
Proceeding has been submitted to NIM-A for publications (in revision).

5 Acknowledgments

We would like to thank whole JLAB Hall-D collaboration, in particular E. Chudakov, for their continues support during a test beam period.